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Use of Agent-Based Modeling in Selecting a Homeland Sensor Network System Concept

Military Operations Research Society (MORS) Symposium

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NAVSEA WARFARE CENTERS DAHLGREN

June 2007

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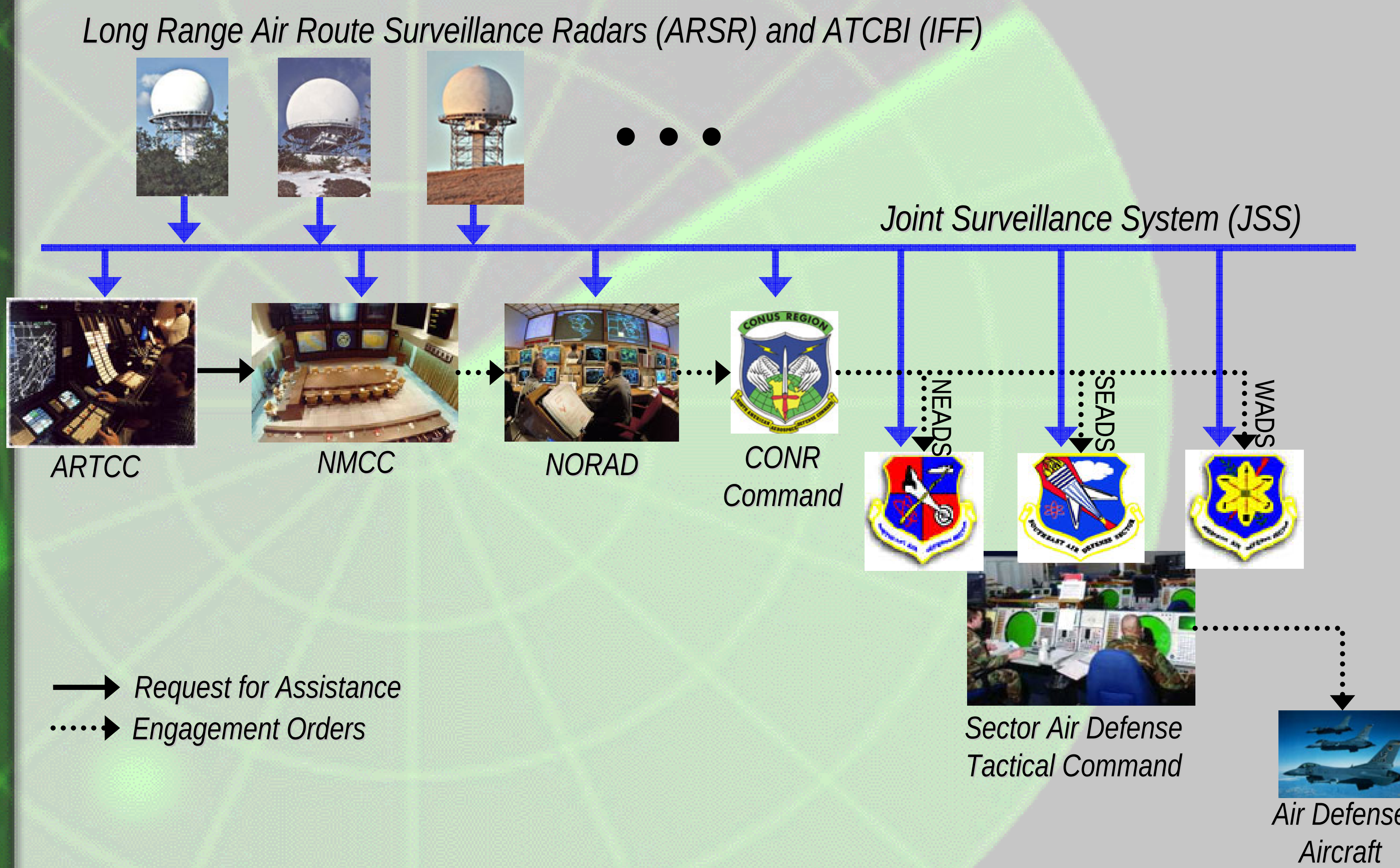
Background

- George Mason University Systems Engineering project
  - Could the integration of sensors address DoD surveillance capability gaps that currently exist in the continental US (CONUS)?
  - Inspired by Military.com article, “DoD Finds Cruise Missile Defense Gaps,” 17 Aug. 2006
- NSWCDD engineering team
- Agent-based modeling employed as part of the early systems engineering process
- Scope of analysis constrained to Northeast US

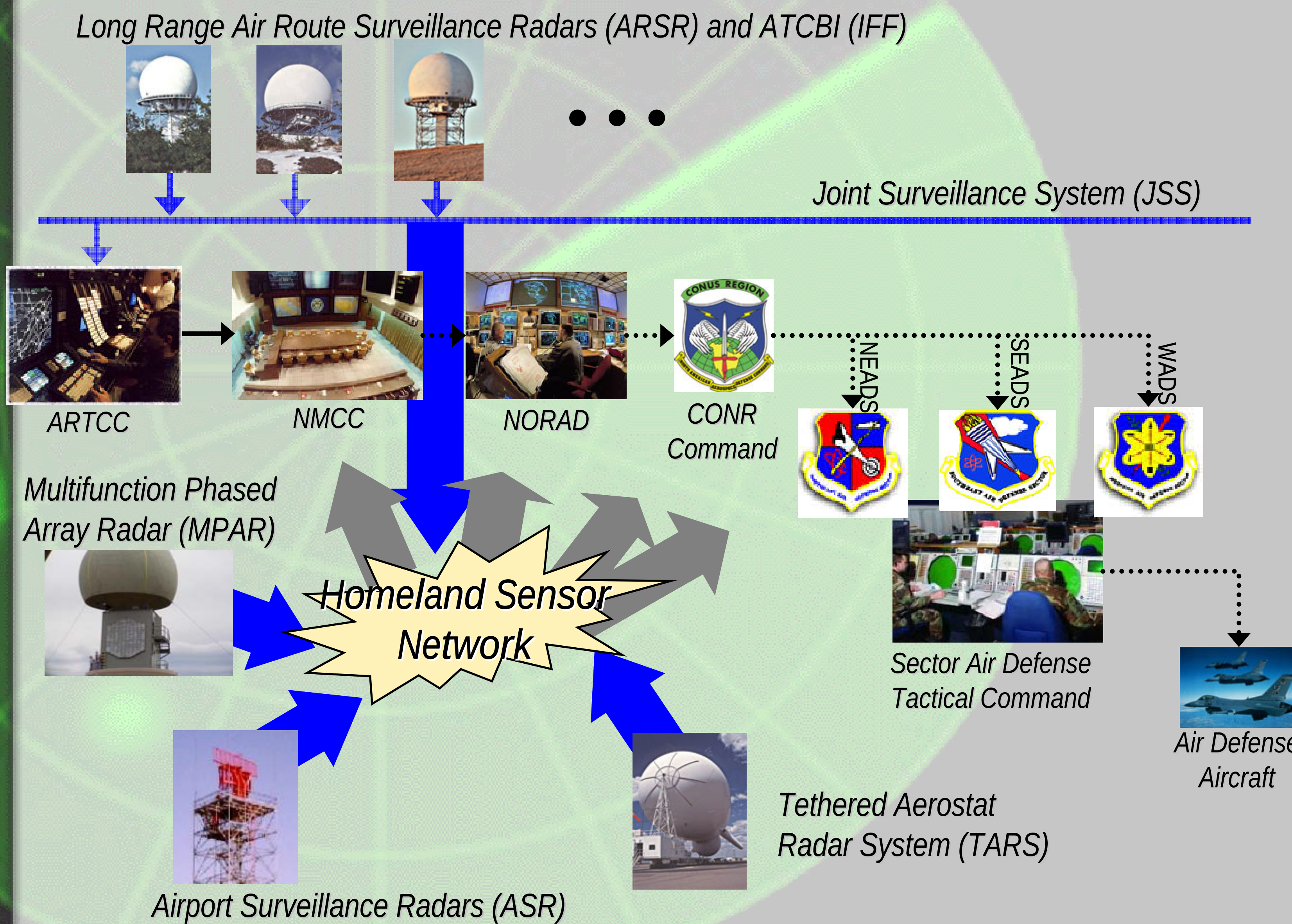
Current Situation



ARTCC – Air Route Traffic Control Center
NORAD – Northern American Air Defense Command
NEADS – Northeastern Air Defense Sector
WADS – Western Air Defense Sector

NMCC – National Military Command Center
CONR – Continental US (CONUS) NORAD Region
SEADS – Southeastern Air Defense Sector

Homeland Sensor Network (HSN) System Options



Systems Integration Options
(DC Capital Region IOC)

1. Do Nothing. Live with Standard Operational Procedure (SOP) to fly Airborne Early Warning Aircraft (e.g. AWACS) and/or deploy Sea-based sensors (e.g. Aegis ships) for increased sensor capability

2. Integrate Airport Surveillance Radars (ASRs)

3. Procure and Integrate a Phased Array Sensor at a military facility close to DC Capital Region

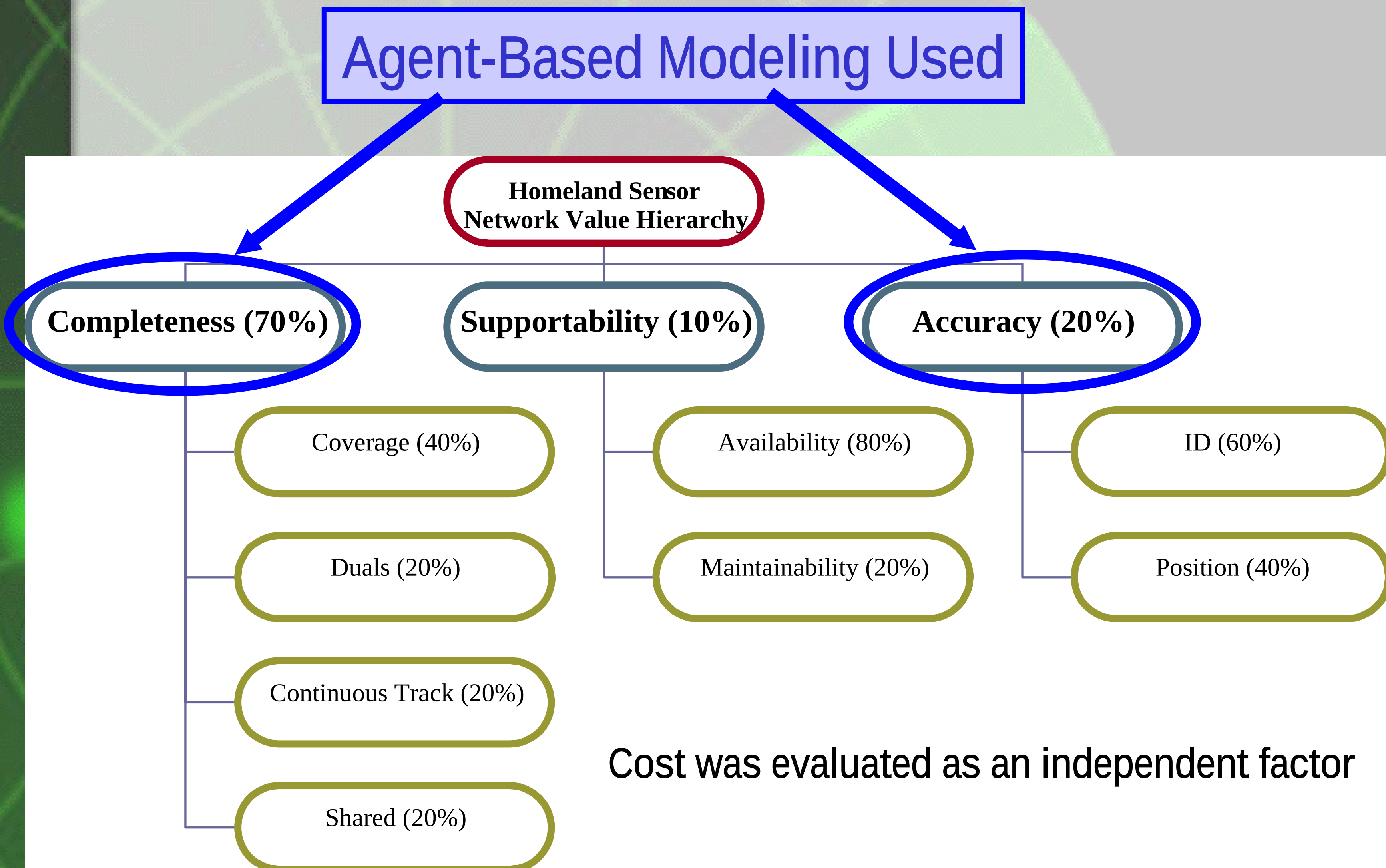
4. Procure and Integrate Tethered Aerostat Radar Systems (TARS) at military facilities close to the DC Capital Region

5. Combinations of the above options

Engineering Process

- Defined metrics:
  - Value Hierarchy
  - Key Performance Parameters
  - Measures of Effectiveness and Performance (MOEs/MOPs)
- Developed alternative system architectures
- Developed agent-based model architecture
- Refined model details
- Ran model once matured
- Performed statistical analysis
- Estimated cost, maintainability and reliability
- Drew conclusions
- Made recommendations

HSN Value Hierarchy & Agent-Based Modeling



Cost was evaluated as an independent factor

Agent-Based Modeling Platform

- What is it?
  - Multi-agent programming language
  - Integrated modeling environment
  - Audience: teaching and research
- Who develops it?
  - Center for Connected Learning and Computer-based Modeling, Northwestern University
- What does it support?
  - Rapid model development
  - Statistical experiments
- What else is important?
  - Free
  - Cross-platform (Java)
  - Large and active user community

Modeling and Analysis Approach

Agent-Based Performance Model

- Control experiment factors
- Simulated aircraft flight profiles
- Simulate sensor (IFF and radar) detections
- Model sensor detection errors
- Generate sensor report file

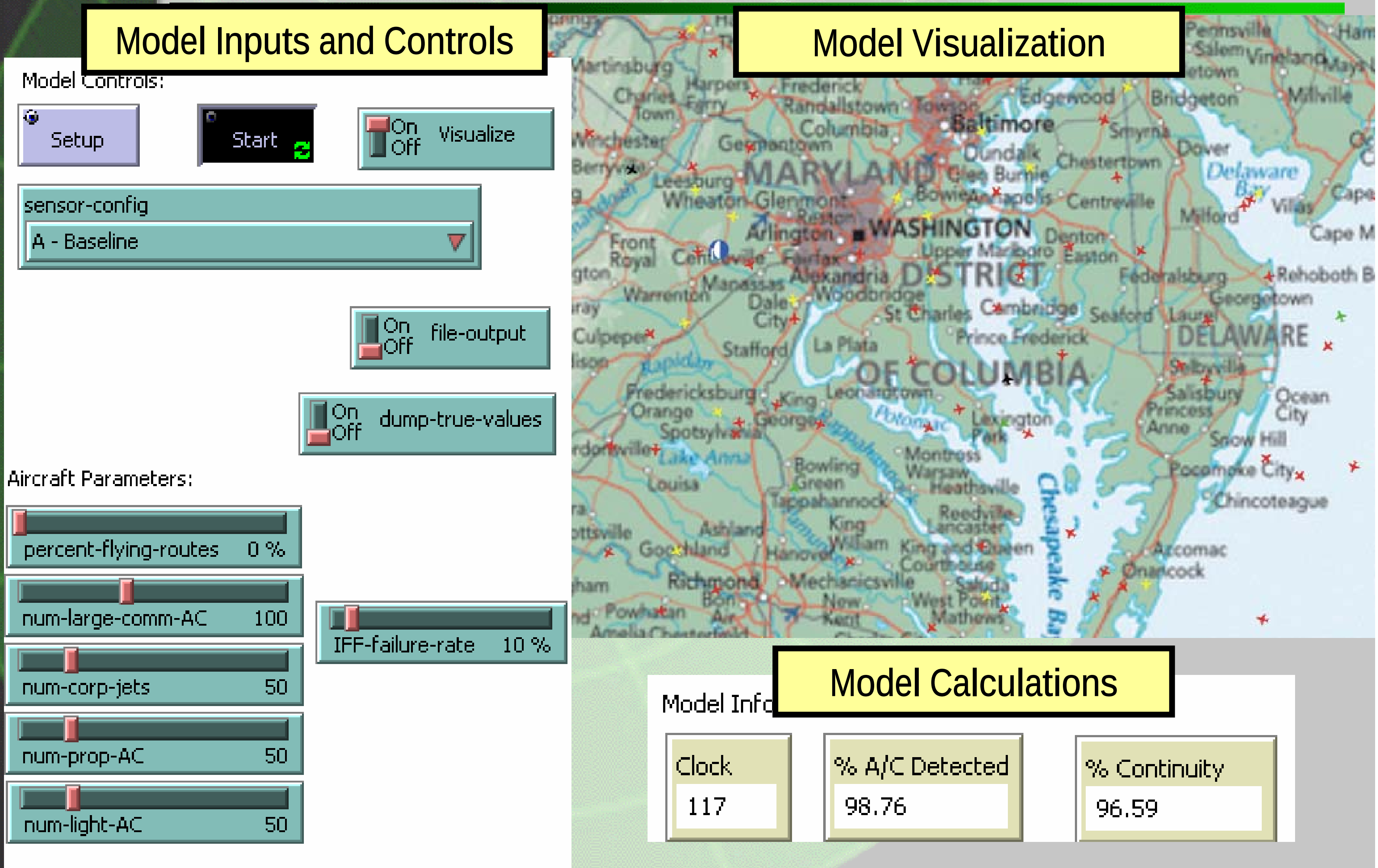
- Real-time calculation of MOPs:
  - Coverage
  - Continuity

Data Analysis Program

- Correlation of sensor reports (tracks) from multiple sensors
  - In accordance with MIL-STD 6016 (Link 16)
- Calculate FAA picture

- Offline calculation of additional MOPs:
  - Shared
  - Dual tracks
  - ID accuracy
  - Position accuracy

HSN Performance Model



Model Design

- Aircraft randomly placed across airspace
- Sensors read from input file
  - Primary radars
  - Secondary radars (beacons)
- Sensor-to-aircraft range checks
- Sensing modeled using probability distributions
  - Detection
  - Accuracy (range, azimuth, altitude)
- Accuracies calculated:
  - Position, speed, course
- Aircraft colors changed based on detection
- Simulation cycle:
  - Sense Aircraft
  - Move Aircraft
  - Move Sensors
  - Update Display

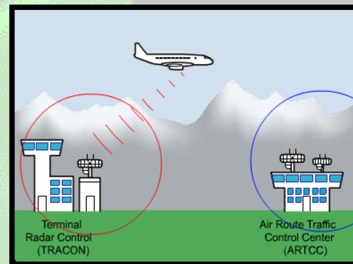
Experimental Factors

Aircraft Density

Aircraft Types:
- Large Commercial
- Corporate Jets
- Private Prop A/C
- Light A/C

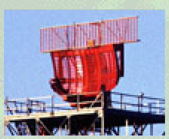
Aircraft Behavior

Beacon (IFF) Failures



Measures of Effectiveness

Baseline

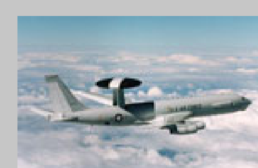


ASRs

TARS

MPAR

Supplemental Sensors:
- AWACS
- Aegis Ship



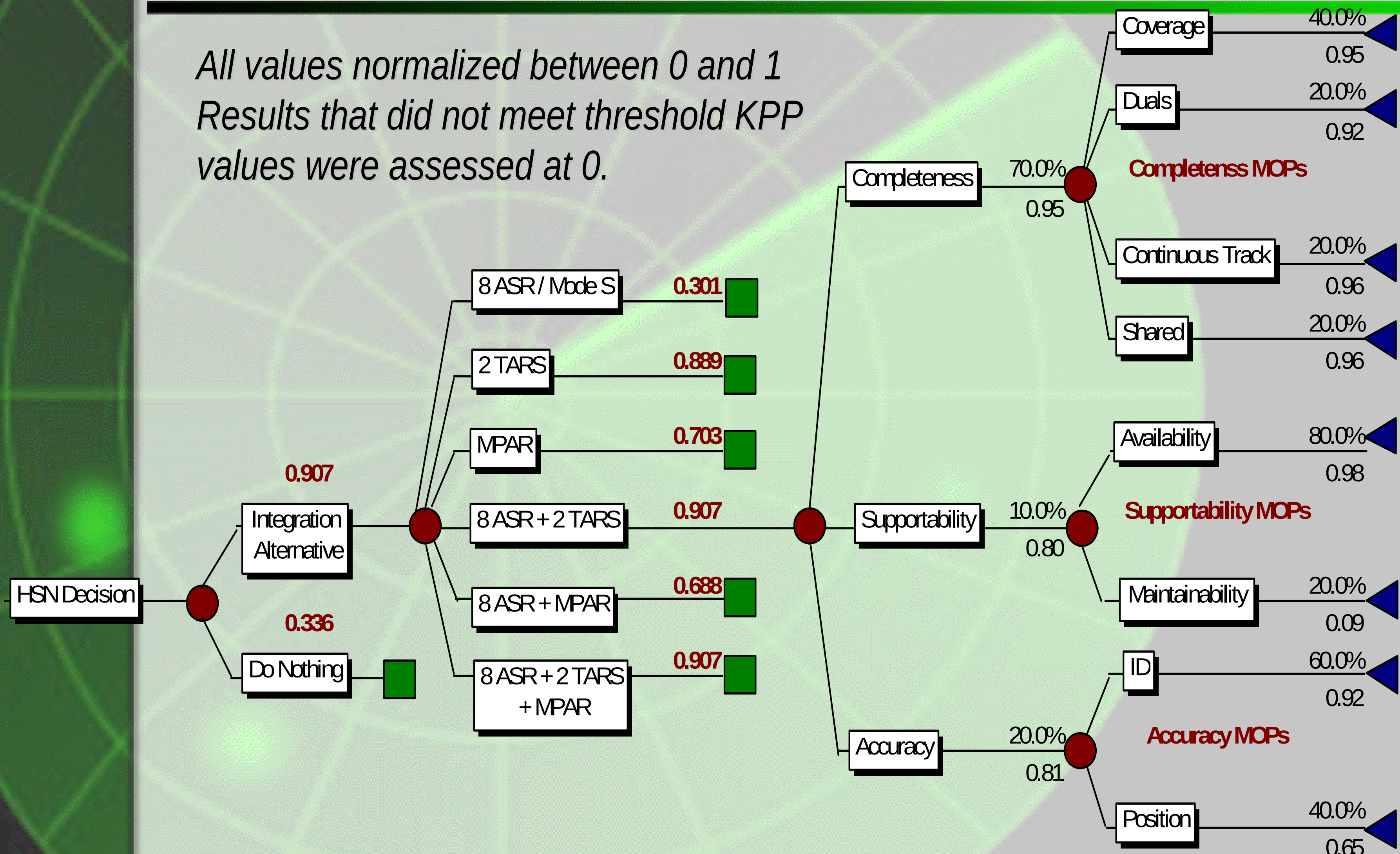
System Integration Alternatives

System Configurations Analyzed

	Sensors Integrated						
Name	ARSR-4	ASR-9	Aerostat (TARS)	Land-Based Phased Array Radar	AWACS	Aegis Ship Radar	Track Correlation Capability
Baseline	X						JSS (Uncorrelated)
Baseline + SOP	X				X	X	JSS supplemented w/ correlated data
ASR Integration	X	X					JSS supplemented w/ correlated data
ASR + SOP	X	X			X	X	JSS supplemented w/ correlated data
Aerostat Integration	X		X				All sensor data correlated
Land-Based Phased Array	X			X			All sensor data correlated
ASR + Aerostat	X	X	X				All sensor data correlated
ASR + Phased Array	X	X		X			All sensor data correlated
ASR + Phased Array + Aerostat	X	X	X	X			All sensor data correlated
All Sensors	X	X	X	X	X	X	All sensor data correlated

Decision Analysis Tree

All values normalized between 0 and 1
Results that did not meet threshold KPP values were assessed at 0.



Two Options Meet Objectives Prior to Consideration for Cost

Normalized Scores for Measures of Effectiveness

Integration Options	Completeness (NV)	Accuracy (NV)	Supportability (NV)	Alternative Results	Cost
Baseline	0.24	0.33	1.00	0.336	$0
8 ASR / Mode S	0.19	0.40	0.85	0.301	$1.0M
2 TARS	0.98	0.55	0.95	0.889	$8.9M
MPAR	0.64	0.79	0.98	0.703	$12.4M
8 ASR + 2 TARS	0.95	0.81	0.80	0.907	$9.2M
8 ASR + MPAR	0.64	0.80	0.84	0.688	$12.7M
8 ASR + 2 TARS + MPAR	0.96	0.78	0.78	0.907	$21.0M

NV – Normalized value from 0.000 to 1.000

Alternative selected based upon Decision Analysis and Cost as an independent factor

Analysis Conclusions and Recommendations

- Could the integration of sensors address DoD surveillance capability gaps that currently exist in the continental US (CONUS)? (YES)
  - Do nothing option does not meet KPP requirements
  - Integration of the JSS with 2 TARS and 8 ASR sensors provides the best capability to meet KPPs at a reasonable cost
- Proceed with next Phase of Homeland Sensor Network (HSN) development
  - However, a detailed performance assessment with classified data and a higher fidelity model is recommended at the beginning of the next phase

Agent-Based Modeling (ABM) Lessons Learned

General

- Worked well for the problem
- Was valuable as part of an overall engineering process
  - Early assessment of critical performance factors on a large, distributed system problem
  - Required system architectures and requirements as inputs to model design
- Forced detailed review of Measures of Effectiveness
- Forced increased understanding of system alternatives

NetLogo Modeling Platform

- Supported rapid model development and changes
- Provided direct support for experimental factors
- Required off-line data analysis
- Would not support detailed radar performance analysis

Questions?

Recent Pentagon Assessment

"Pentagon assessment of U.S. capability to defend the homeland … has found what it calls 'capability gaps'…"

- Military.com (August 06)

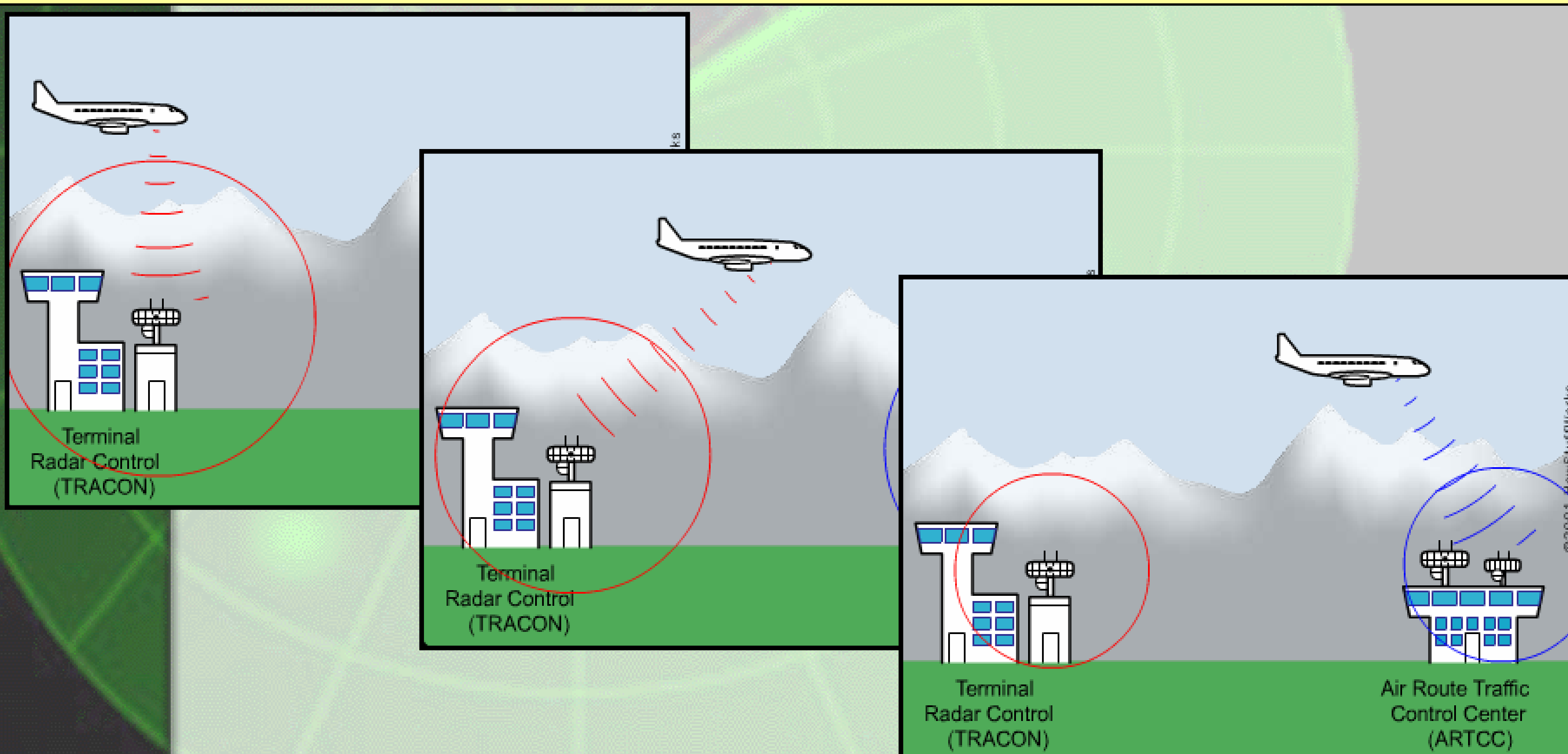
- ✓ No common operating picture
- ✓ Insufficient surveillance coverage of NORAD's area of operations
- ✓ Inability to detect small, low-speed, low-altitude targets
- ✓ Inability to automatically fuze information from Wide Area Air Surveillance family of systems
- ✓ Air defense sensors' inability to reliably provide adequate tracking information
- ✓ Air defense sensors' inability to determine the intent of an aircraft with 100% reliability
- ✓ Inability of sensor system to provide enough information for military officials to make "engagement decision recommendation"
- ✓ Inadequate supply of information to NORAD analysts from other government agencies
- ❑ *Not enough weapons-delivery platforms available to cover North American continent*

Scope of Analysis

- Limited to Air Traffic Control Areas:
  - ZDC (Washington)
  - ZOB (Cleveland
  - ZNY (New York)
- Limited to States
  - Virginia
  - Pennsylvania
  - New York
  - West Virginia
  - District of Columbia
  - Maryland

How Aircraft are Tracked Today
(IFF Example – Primary Means)

Once a plane takes off, your pilot activates a transponder device that detects incoming radar signals and broadcasts an amplified, encoded radio signal in the direction of the detected radar wave. The transponder signal provides the controller with your **aircraft's flight number, altitude, airspeed and destination.** A blip representing the airplane appears on the controller's radar screen with this information beside it. The controller can now follow your plane.



HSN Key Performance Parameters (KPPs) Originating Requirements Document

MOE	MOP	THRESHOLD	OBJECTIVE
(1.0) Completeness	(1.1) Coverage: The HSN shall support ___ tracking of all objects.	95%	98%
	(1.2) Duals: The HSN shall provide less then ___ duals.	5%	3%
	(1.3) Continuous Track: For each aircraft tracked, the HSN shall hold contact ___ of the time.	95%	98%
	(1.4) Shared: The HSN shall provide a ___ common (shared) track picture among critical military National, Operational, and Tactical Command and Control (C2) nodes.	95%	98%
(2.0) Supportability	(2.1) Availability: The HSN shall have an availability of _____.	99.999%	99.999%
	(2.2) Maintainability: The HSN shall be maintainable by 2 operators with a mean time to repair of __ hours.	8	4
(3.0) Accuracy	(3.1) ID: Track identification shall be ___ percent accurate.	90	95
	(3.2) Position: HSN track position accuracy shall be accurate within __ nautical miles.	5	3

Decision Analysis Approach

- Completeness and Accuracy MOE results derived from performance modeling and data analysis program.
- Supportability MOE approach:
  - Maintainability: based upon number of site for each design solution – i.e. more sites equates to more time required for troubleshooting and repairs.
  - Availability: calculation based upon system redundancy of each solution.

$$Availability = [1 - (1 - A_{sensor})^{N_{sensor}}]$$

A_{sensor} = (design) specified availability of each sensor (e.g. TARS = 0.98)
N_{sensor} = number of overlapping sensors (e.g. 2 TARS with overlapping coverage)